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The fatigue effects of sustained concentration on visual performance

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Abstract

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THE FATIGUE EFFECTS OF SUSTAINED CONCENTRATION ON VISUAL PERFORMANCE

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ABSTRACT

Certain functions of the visual system may be affected by sustained cognitive demand tasks which are common in non-dynamic sports such as pistol shooting, diving, golf and others. 31 undergraduate and 9 graduate students from Pacific University were visually evaluated before and after a thirty-minute period of intense cognitive activity. The test battery consisted of four visual evaluation areas: Contrast sensitivity, stereosensitivity, fixation disparity, and a perceptual speed task. A set of 480 simple addition and subtraction equations were used as a cognitive task to induce fatigue.

Data analysis revealed significant differences in post-fatigue trials in all areas evaluated except contrast sensitivity. It was found in post-fatigue trials that fixation disparity became less exo, perceptual abilities on a speed task improved, and stereosensitivity decreased. These changes were attributed to a heightened cognitive level secondary to the mental task. It was the goal of this study to simulate non-dynamic sport conditions by inducing mental fatigue. The visual changes found in this study may contribute to inconsistent performance in non-dynamic sports which emphasize concentration that induces mental fatigue.

INTRODUCTION

Athletes from every discipline of sport rely on their vision in some way to obtain their desired results. From the racecar driver shifting gears while keeping his eyes on the raceway, to the competitive diver standing on the dive platform, to the international pistol marksman shooting a particular competition, all in some way rely on their vision for optimal performance. Visual cues, to some degree, are neccessary no matter what the sport.

Athletes and coaches have been concerned about possible visual changes which may occur secondary to mental fatigue encountered during the prolonged periods of competition which occur in many non-dynamic sports. For example, during a free pistol competition, the competitor fires 60 shots at a stationary target over a period of time not to exceed 2 1/2 hours. Each shot is mentally rehearsed in the competitor's mind prior to each shot delivery reflecting the intense concentration required. In contrast, the rapid-fire pistol competitor fires five shots, one on each of five separate targets 25 meters away. The shooter signifies when he is ready. After a three second delay, all five targets turn toward the competitor who must raise his pistol from a 45 degree angle and shoot one shot on each of the five separate targets. The shooter has 8 seconds to shoot these five shots on the five targets before they turn away. This is repeated again at 8 seconds, then the shooter fires two, 5-shot strings within a 6 second time limit followed by two, 5-shot strings within a 4 second time limit. Shot rehearsal and mental preparation are paramount to successful training and competition.

Researchers have explored the effects of physical exercise on various mental abilities. Although needed research, it has dealt only with our physical and mental abilities while at or near an aerobic threshold during physical exercise. Little research has been directed specifically towards the effects which may take place in the visual system under such conditions. The effects on the visual system during non-dynamic sport have not been examined while the subject's cognitive processing system is in a state of induced fatigue secondary to concentration. Sports emphasizing concentration frequently involve one competitor competing by himself and, as such, require a high degree of attentional control which may yield an induced fatigue effect.

In the past there have been no studies that have evaluated the effects of prolonged concentration on visual performance. Fatigue from this prolonged concentration may affect visual performance depending on the type of competition and its duration.

In a study using a similar cognitve task to that employed in the current study, Jaschinski-Kruzan and Toenies studied the effect of mental arithmetic on the dark focus of accommodation. It was found that subjects whose initial accommodative posture was farther toward their far point responded with a greater shift inward during the mental task. Those subjects with a closer dark focus point of accommodation had a smaller inward shift.[1] In contrast, Malmstrom, Randle, Bendix and Weber did a similar study and found that their subjects' accommodative shift was in the direction of the subjects' visual farpoint. It was found that the shift was less pronounced when objects were presented in the periphery rather than foveally.[2]

This study is an exploratory investigation of measurable changes in visual performance which occur in association with mental fatigue. Studies in the past have investigated the effects of physical exercise on vision and mental performance. Davey found improved performance on mental tasks after physical activity.[3] This effect was also tested by Hancock and McNaughton who found that short-term memory and low level cognitive abilities improved in subjects in a physically fatigued state. When these subjects reached their anaerobic threshold, it was found that these capabilities decreased. Anaerobic threshold was defined in the study as a rise in ventilation utilizing an applied oxygen-carbon dioxide analyzer which electrochemically analyzed each subjects breath. All high-level and low-level cognitive abilities decreased when the anaerobic threshold was passed and a marked narrowing of the peripheral field occurred.[4]

Given the limited published research in the area, our experimental hypothesis is non-directional and states only that we expect change in the measured variables associated with the cognitive task. Despite this, we attempted to predict changes in measurement variables based upon personal experience and visual neurophysiology. Fixation disparity under fatigued conditions may become less exophoric due to the activation of sympathetic innervation associated with a stress response. This innervation results in increased accommodative convergence secondary to an initial inhibition in accommodation yielding a less exophoric posture.[5] When an individual is not as "alert or sharp," their ability to accurately perform a form recognition task may be decreased due to the fatigued state secondary to mental concentration. Contrast sensitivity and grating resolution may also be compromised in a fatigued state as a result of the net inhibition and possible fluctuation of accommodation. This may be the result of an inability to accurately focus with the accommodative system toward the plane of the test stimuli. Likewise, as the subjects become more fatigued due to cognitive concentration, stereo-sensitivity may become more variable. This may also be related to the sympathetic innervation of the accommodative system.[6] When the cognitive induced fatigue occurs and a stress response ensues, our vergence posture may become less stable and hence, the net effect may be a less precise vergence alignment.

METHODS

Subjects

The data for this research were obtained from a group consisting of 31 undergraduate students attending Pacific University and 9 graduate students attending the Pacific University College of Optometry. The subjects were males ranging from 18 to 26 years of age with a mean age of 20.6 years. The sample included athletes and nonathletes with various levels of academic experience. Upon arrival for testing the subjects were administered a three part screening test which consisted of static distance visual acuity, depth perception, and a cover test. Inclusion criteria for participation were: six meter visual acuity of at least 20/25 O.U., six meter stereoacuity of 240 arc seconds (correct response within a time limit of 12 seconds), and no apparent strabismus upon cover testing. The subjects also completed an informed consent form and a brief questionnaire concerning ocular and general health history.

Procedure

The subjects were divided into two groups of 20, and both groups underwent the same experimental conditions; however, in order to control for possible practice effects, the order of the testing was different between the two groups (Figure 1). The test battery consisted of four visual evaluation areas, following which Group A was administered a 480-question simple addition and subtraction cognitive task, which was followed by a readministration of the four visual tests. Group B underwent the simple addition and subtraction cognitive task first, followed by the test battery, not being exposed to the test battery prior to the cognitive task. The subjects in Group B returned the next day to perform the test battery alone. The data collected the day after the mental fatigue task constituted the "pre-fatigue" data for Group B. The test battery was performed in the order discussed below.

Individual testing protocol was established for each of the tests performed. The protocol was developed using the Pacific Sports Visual Performance Profile (PSVPP) system and will be described in a similar manner.[7] The abbreviations used in the protocols are as follows:

E: Evaluates. Definition of the primary ability evaluated by the test.

TD: Testing distance.

IL: Illumination level.

P: Positon of subject.

CF: Critical factors to be observed in administering the test.

IS: Instructional set.

R: Recording.

Fixation Disparity

Horizontal fixation disparity was measured using a prototype Sheedy Distance Disparometer (see Figure 2).[8] The device is similar in design to the more familiar near (40 cm) Disparometer but is calibrated for use at 4 meters. The measurement was performed twice, once starting from crossed disparity and once starting from uncrossed disparity.

E: Horizontal fixation disparity.

TD: Four meters.

IL: 17 foot-candles.

P: Sitting relaxed.

CF: Make sure the subject's head remains in the primary position of gaze. Make sure the polaroid lenses cancel correctly. The vernier line is moved at a constant rate of 1/2 inch per second.

IS: "Look directly at the center of the target. You will notice a vertical line or vertical lines in the center. When I occlude this eye does one line disappear and one remain? Which line disappears, the bottom or the top? When I occlude the other eye does the same thing happen with one line disappearing and the other remaining? Again, which line disappears, the bottom or the top? I will be moving the top line towards the other line once from each direction. I want you to tell me immediately when they first become aligned (one directly above the other) by saying "now" as quickly as you can."

R: Record the amount of disparity between the vernier lines for each of two trials. Fixation disparity mean is the average of the two measures, fixation disparity test-retest range is the difference between the two measures.

Perception Speed Task

The Perception Speed Task was performed with the use of test stimuli taken from the Structure of Intellect Learning Abilities Test,[9] subtest CFT, which were converted into slide form for projection and testing at six meters. Two different sets of slides were used for testing. One set for pre-fatigue (Form A) and one set for post-fatigue (Form B) to control for any possible learned effect.

E: Quality and speed of central visual information processing on a form recognition and matching task.

TD: Six meters.

IL: 17 foot-candles.

P: Sitting relaxed.

CF: Stimuli consist of twenty-seven form recognition and matching slides. There will be one demonstration slide.

IS: "I'm going to show you a series of shapes located on the left-hand side of the screen. When the slide is presented I want you to look at the shape on the left and locate its exact match in the row directly to its right. The shapes may be rotated. Once you locate it say the number of shapes it is away from the first. Then we will proceed to the next slide immediately. It is important to proceed as quickly and as accurately as possible during testing."

R: Record the subject's responses during the two-minute test period. For each set of slides, calculate and record the number of correct responses and the percent of responses correct for future evaluation.

Contrast Sensitivity (Nicolet)

Contrast sensitivity was measured binocularly using the Nicolet Optronics CS 2000, a video-based contrast sensitivity device. After calibration and set-up, an increasing-contrast (unseen-to-seen) grating pattern was used with three repeats at each spatial frequency tested. This is a more reliable method of measuring contrast sensitivity in the population as a whole.[10] A preview to the pattern was provided for the subject prior to testing at each spatial frequency. Stationary grating patterns were presented to the subjects at spatial frequencies of 15, 18, and 21 cycles per degree with an initial contrast setting of .002 at each frequency.

E: Visual contrast sensitivity.

TD: Three meters.

IL: 17 footcandles.

B: Sitting relaxed.

CF: Patient is instructed to fixate the screen the entire time of testing and to respond when the gratings become visible.

IS: "While fixating the circular screen, you are to indicate when you first identify a grating pattern on the monitor by pressing the button on the hand control. There will be two beeps before the practice pattern and one beep before the trial pattern".

R: Collect the computer print-out when testing is completed for future evaluation.

Stereosensitivity (Howard Dolman)

Stereosensitivity was tested with the Howard-Dolman apparatus using a modified technique of measure to approximate stereothreshold. The test was performed twice from each direction with the movable peg being manipulated by the tester starting behind and in front of the stationary peg. The peg was moved at a constant rate of 1/2 inch per second until the subject first perceived alignment between the two pegs .

E: Stereosensitivity in free space. Designed for far point measurements.

TD: Six meters.

IL: 17 foot-candles.

P: Sitting relaxed.

CF: Patient is instructed not to move their head so that lateral parallax is not induced.

IS: "This test consists of one movable vertical rod viewed through an aperture against a white background. The movable rod will be slowly adjusted fore and aft. Your task is to determine when the two rods appear to be equally distant (in the same plane) as demonstrated by my fingers. Please respond by saying "now" when the two rods appear to be in alignment. It is extremely important to keep your head and body still during the testing." Demonstrate with fingers (4 trials).

R: Record the separation distance of the two rods in millimeters for future conversion into seconds of arc (stereoacuity).

The test battery was performed in the order listed above.

Cognitive Task

Subjects were administered a mathematical simple addition and subtraction equation set containing 480 questions. The equation solutions all equalled under 100 with approximately 1 to 1.5 seconds between problems. The equations contained an even number of subtraction and addition problems and were also developed to contain an equal number of jumps between number groups. (a number group in this example would be the 20's, 30's, 40's etc.). Examples of equations used are as follows: 19+4, 90-4. The equation set was played on an audio cassette for the subject whose goal was to verbally answer the equations as quickly as possible During the task, the subject was instructed to focus and fixate upon a tic-tac-toe pattern projected six meters away with a visual acuity demand of 20/500. The subjects were also instructed to stay mentally focused on the task and if they fell behind or missed an equation, they were to proceed with the next equation that they heard. The tester recorded responses for analysis upon completion of the research.

Data Analysis

The data for each of the four visual factors were compared using paired t-tests to ascertain any changes in performance associated with the mental fatigue task. Comparisons were also completed to control for possible practice effects related to testing order.

RESULTS

The results are summarized in Table 1. Analyses of data revealed mixed effects between pre-fatigue and post-fatigue subject performance.

Specifically, significant differences were noted in the areas of fixation disparity mean ($p<0.01$), number correct ($p<0.01$) and percentage correct ($p<0.05$) during the perception speed task, contrast sensitivity mean at 18 cycles/degree ($p<0.01$), and in the Howard Dolman mean ($p<0.05$) (Table 1).

Subjects showed a shift of mean fixation disparity toward a less exo posture between pre-fatigue and post-fatigue measures. Fixation disparity test-retest range remained essentially the same after mental task performance (Figures 3a & 3b).

In comparisons of the pre-fatigue and post-fatigue perceptual speed tasks, subjects not only attained higher scores but also scored a higher percentage of correct responses following the mental fatigue. This effect was not due to test-retest learning. Both groups A and B showed better performance on perceptual speed after the fatigue task, regardless of whether it was the first or second exposure to the test procedure (Figures 4a,4b,4c).

The contrast sensitivity measures yielded inconsistent results. Neither the actual level of contrast sensitivity nor the variability in contrast sensitivity differed after fatigue except in the trials at 18 cycles per degree. This measurement showed a decrease in contrast sensitivity after fatigue (figures 5a,5b,5c).

In regard to depth perception, a significant reduction in the ability to perform a distance stereosensitivity task was noted in post-fatigue trials. Distance stereosensitivity became less accurate following fatigue (figures 6a,6b).

DISCUSSION

Fixation disparity can be defined as a condition in which the images of a bifixated object do not stimulate exactly corresponding retinal points, but still fall within Panum's areas, the object thus being seen singly.[11] Fixation disparity can then be related to either an overconvergence (eso posture) or an underconvergence (exo posture).

In the present study, there was a shift in fixation disparity toward a less exo posture subsequent to the cognitive task. The prolonged cognitive task may have elicited a stress response which stimulated the sympathetic nerveous system resulting in pupillary dilation and an inhibition of accommodation. If this sympathetic stimulation actually took place, the accommodative system would have to increase its output to maintain clarity which would cause a secondary increase in convergence due to accommodative/convergence interaction. This increase in convergence could cause a change in fixation disparity to a reduced exo posture.

In non-dynamic sports such as free-pistol shooting, prolonged sport performance would probably not be affected secondary to shifts in fixation disparity. It is unknown whether this minimal shift would affect sports tasks such as a golfer making a long putt, though a relationship between variability in fixation disparity and putting accuracy has been reported.

The perceptual speed task was designed to test subjects' speed and accuracy on a form recognition task before and after performing a cognitive task. In post fatigue testing, subjects displayed a significant increase in their ability to accurately recognize various forms and shapes. The increased perceptual performance immediately following the mental task may be due to heightened cognitive ability secondary to the " mental priming" of the cognitive task. This outcome parallels previously cited work (Hancock and McNaughten) that showed enhanced cognitive ability associated with physical fatigue.

In non-dynamic sport, this enhanced cognitive ability could aid an athlete in form recognition. Mental stimulation prior to an event requiring mental performance and perception may aid the athlete in his task and ultimately increase the level of performance. Similar to physical preparation for an athletic event, mental preparation may increase an athlete's mental preparedness and give the athlete the edge needed for peak performance. In competition such as rapid-fire pistol, a competitor must be able to recognize not only the correct sight picture, but also the correct localization upon the target. The proper sight picture and target localization are formed from an image in the brain and are the focus of the athlete's concentration prior to and throughout the competition. Therefore, mental stimulation prior to competition may increase performance during an event.

Experimentation at the three contrast sensitivity levels resulted in inconclusive data. The only significant change obtained was at 18 cycles per degree. The mental fatigue task does not appear to have had a strong consistent impact upon contrast sensitivity at the spatial frequencies measured in this particular study.

In non-dynamic sports, stereo-localization can be vital to performance outcome. In sports such as archery and golf the visual function of stereosensitivity in free space may allow competitors to be more successful. Data from the research showed a decrease in stereosensitivity in post-fatigue trials. This decreased sensitivity may be secondary to the proposed sympathetic stimulation from the cognitive task and may be directly related to the accommodative/vergence interaction. It is possible that prolonged performance in a non-dynamic sport requiring intense concentration may have negative effects on stereosensitivity. This decrease in stereosensitivity might become an important factor in performance consistency throughout non-dynamic or dynamic sport competition.

There are many variables and factors involved in non-dynamic athletic performance. A part of a competitors' success relies in part on visual function and how they perceive details during performance of the sports task. Consistency throughout competition is also very important to success. This study evaluated 4 visual functions prior to and after an extended cognitive task which required intense concentration. The visual areas tested displayed certain significant flucuations between pre and post-fatigue testing. These changes may impede an individuals overall performance and consistency as the event progresses either by themselves or in conjunction with other variables involved with the specific activity. Enhanced mental as well as physical readiness may be paramount to optimum performance in any discipline of sport.

FLOWCHART

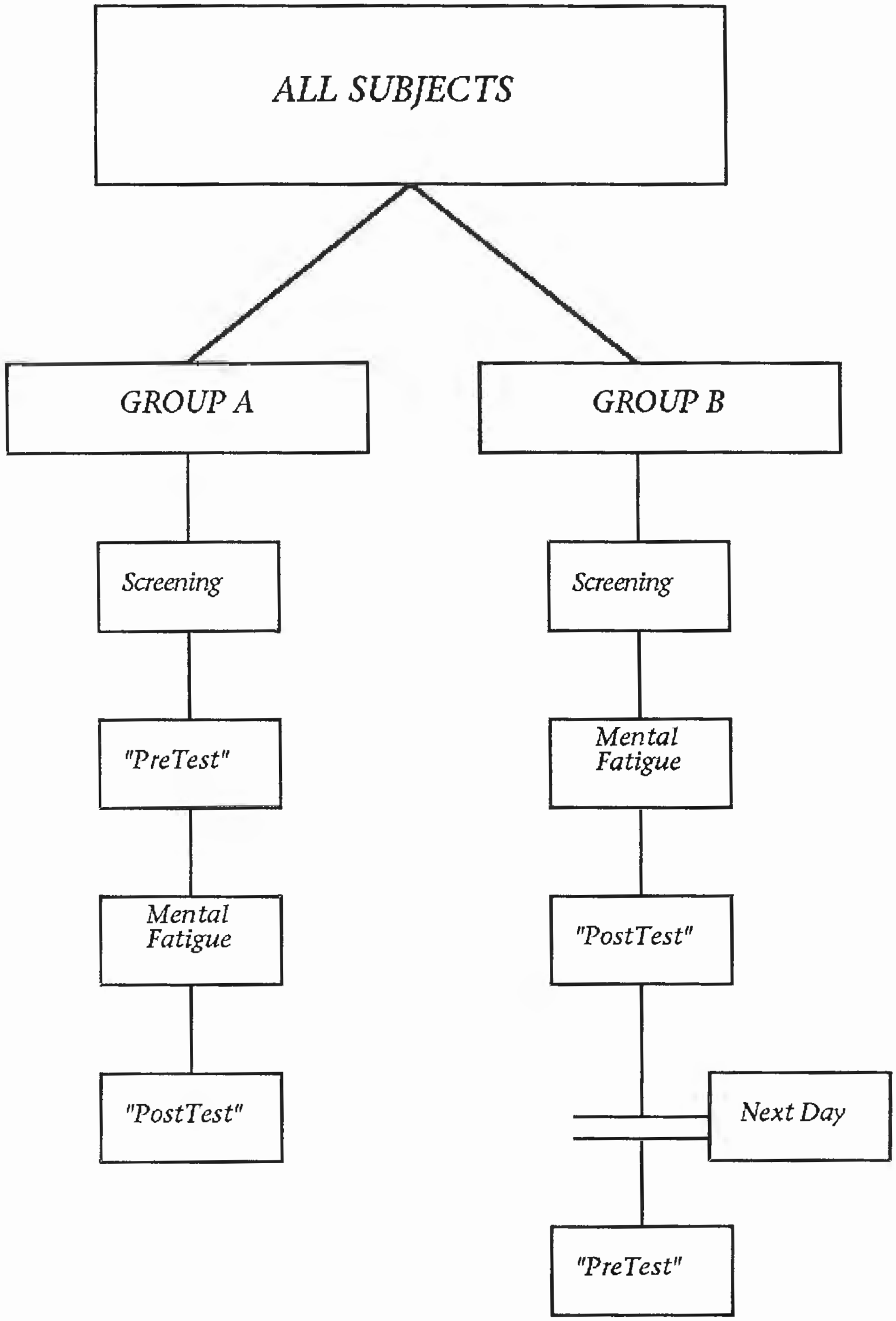

FIGURE #1

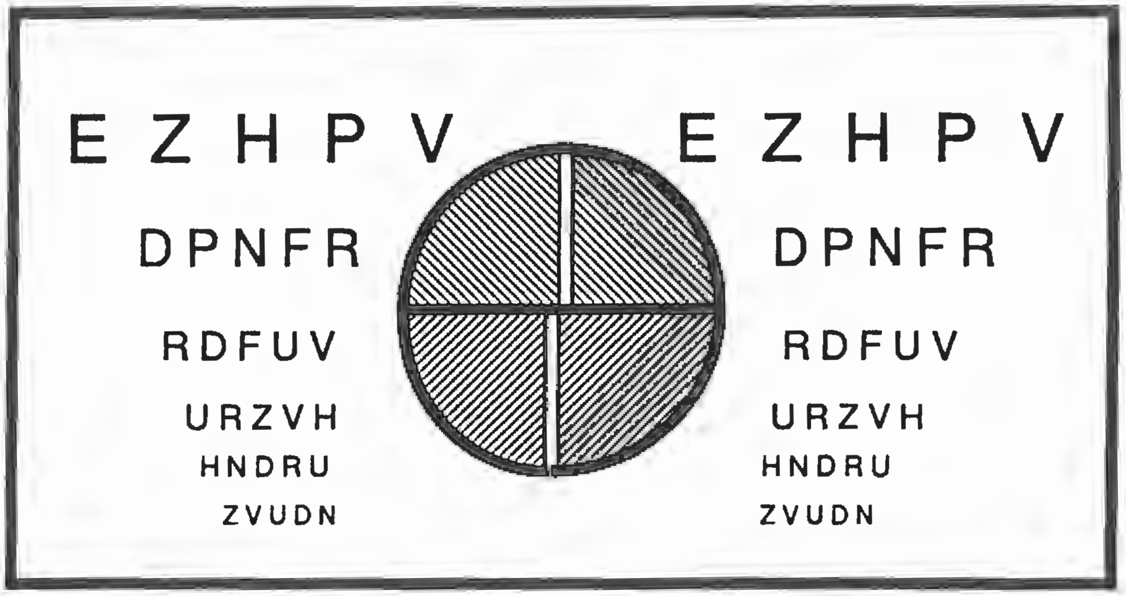

Figure 2. Face of Sheedy Distance Disparometer used to measure fixation disparity. Upper vernier line is seen by right eye, lower vernier line is seen by left eye. The upper vernier line may be adjusted left and right to a position where the subject perceives alignment of the upper and lower verniers.

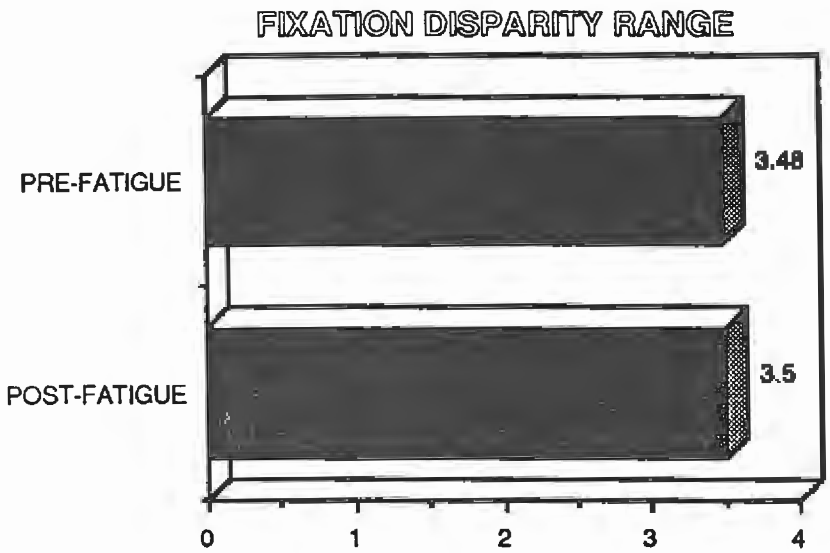

FIGURE #3A

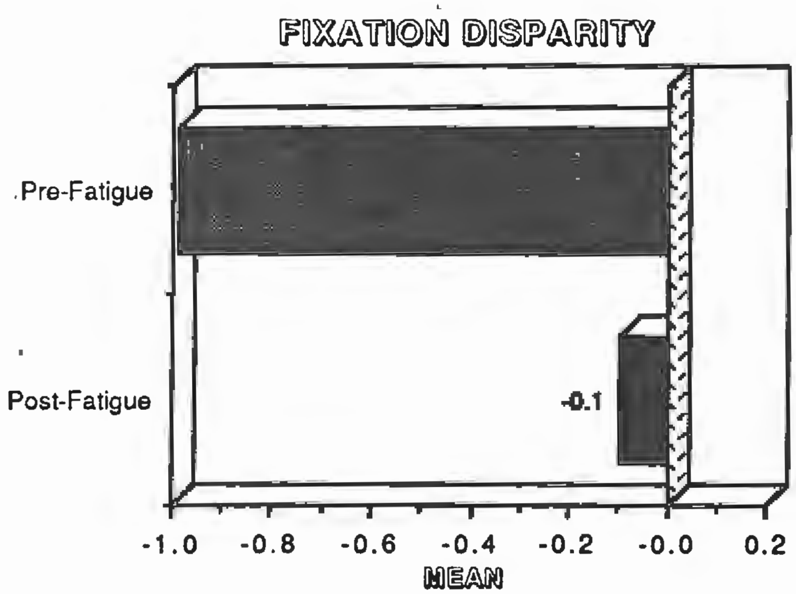

FIGURE #3B

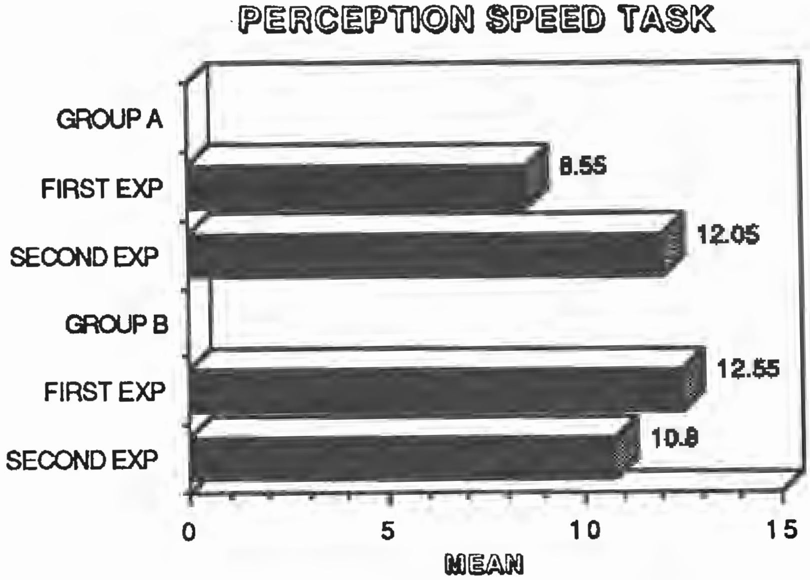

FIGURE #4A

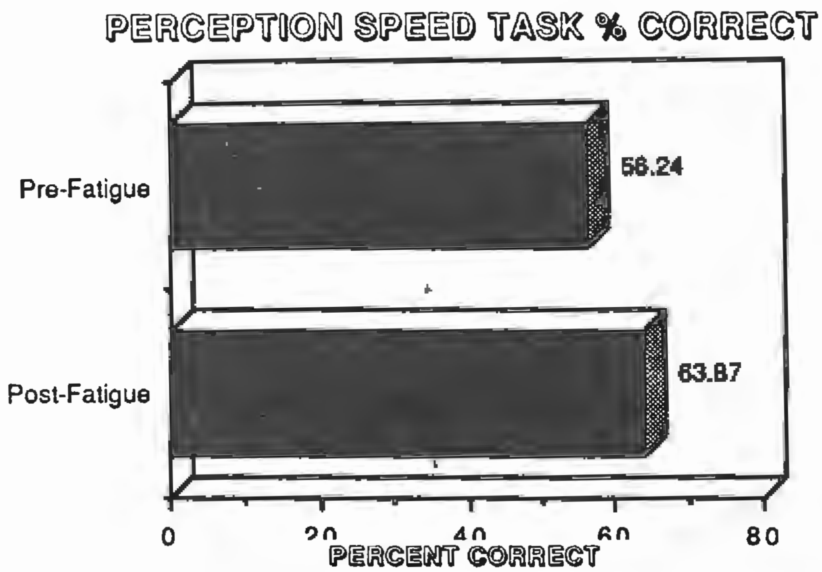

FIGURE #4B

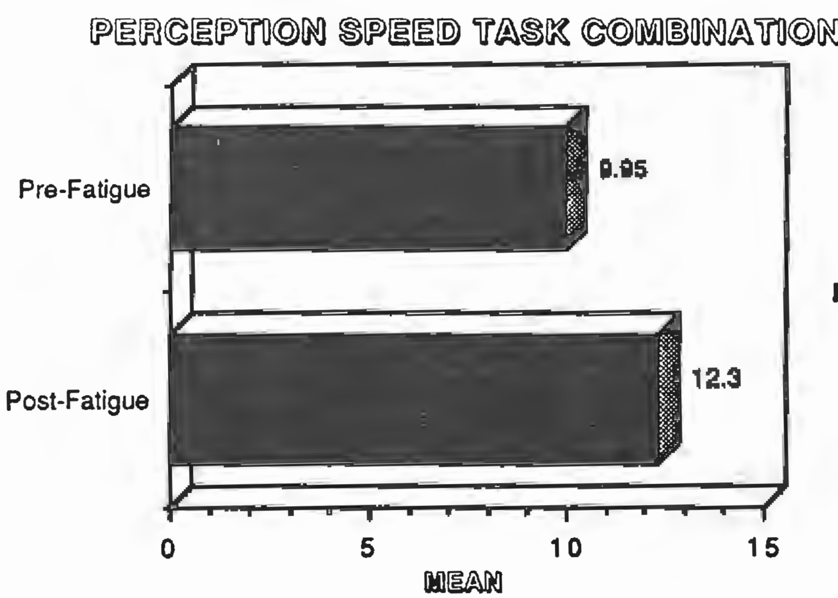

FIGURE #4C

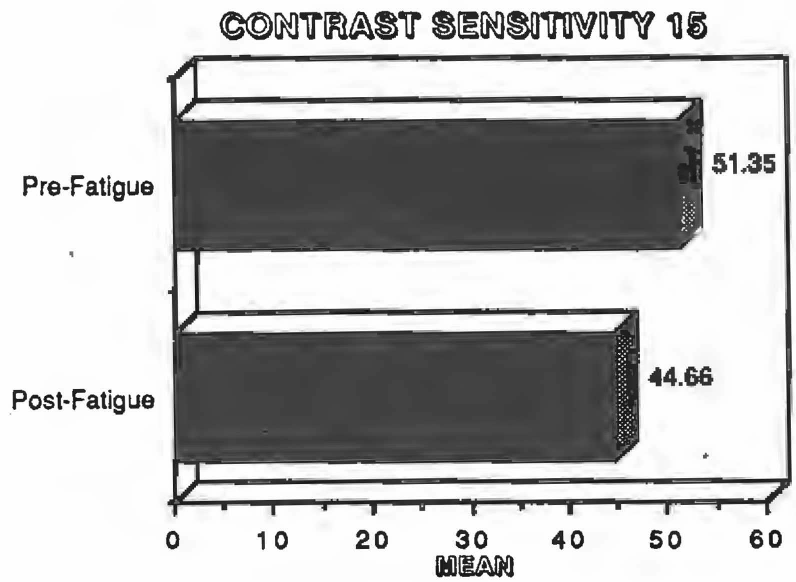

FIGURE #5A

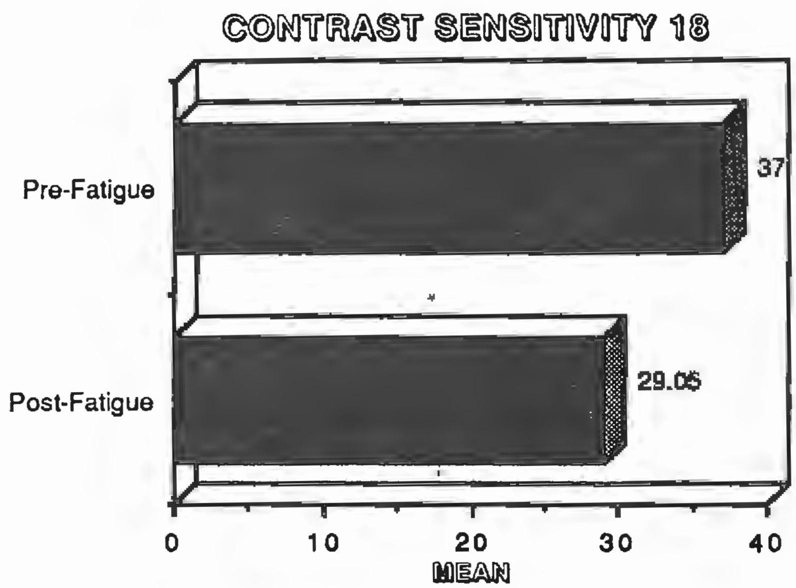

FIGURE #5B

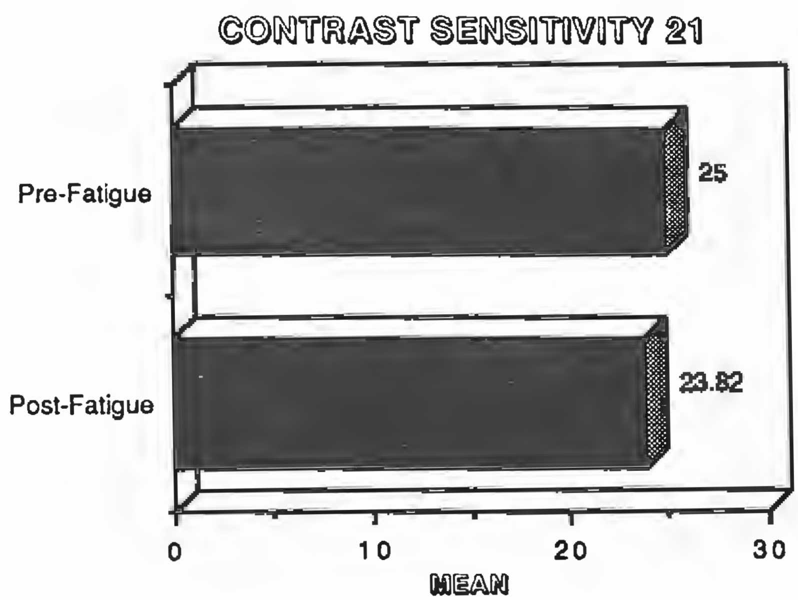

FIGURE #5C

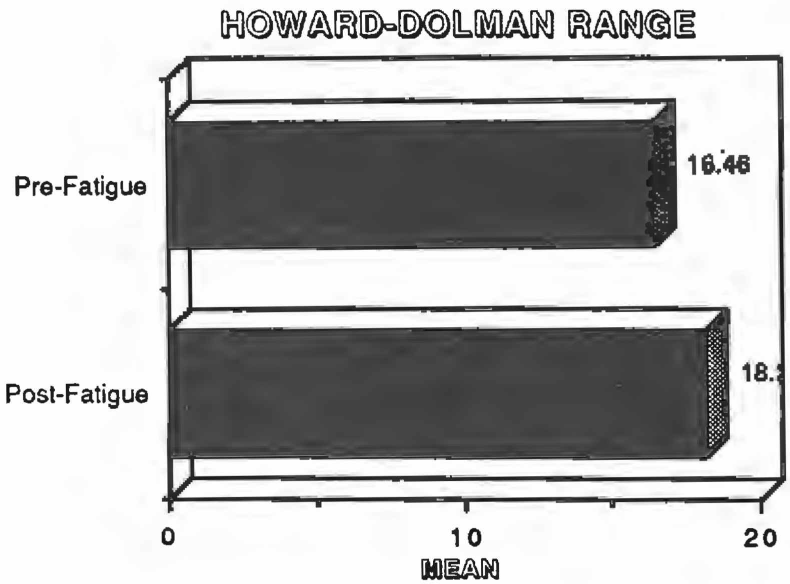

FIGURE #6A

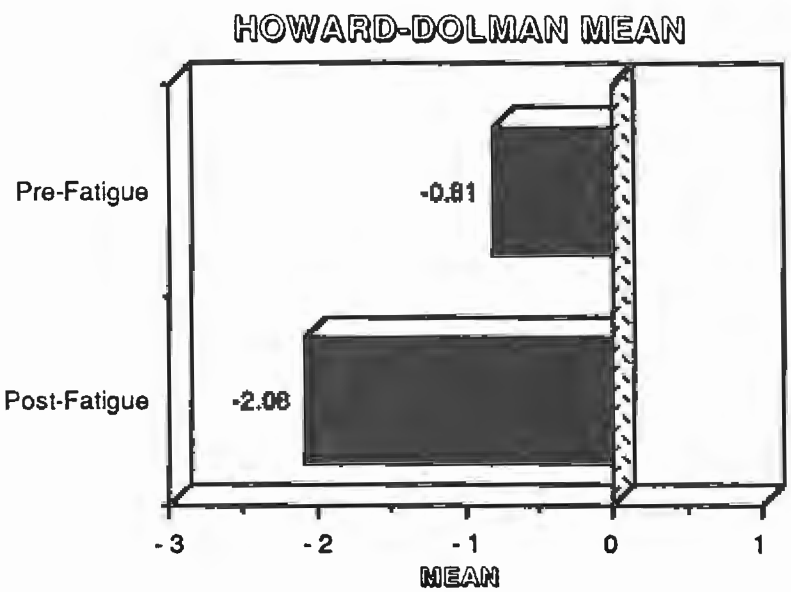

FIGURE #6B

TABLE #1

variable	Units	pre mn	pre s.d.	post mn	post s.d.	prob
fd mn	arc-minutes	-0.99	1.85	-0.10	2.11	0.00
fd rg	arc-minutes	3.48	2.00	3.50	2.23	0.93
pst	# correct	9.95	2.40	12.30	3.31	0.00
pst%	% correct	56.24	14.93	63.87	14.02	0.01
cs 15 mn		51.35	29.62	44.66	18.73	0.13
cs 15 s.d.		0.10	0.08	0.08	0.04	0.14
cs 18 mn		37.14	18.29	29.05	13.66	0.00
cs 18 s.d.		0.08	0.05	0.09	0.05	0.37
cs 21 mn		25.00	11.41	23.82	14.49	0.52
cs 21 s.d.		0.08	0.06	0.09	0.09	0.58
hd mn	arc-seconds	-0.81	2.87	-2.08	2.49	0.02
hd rg	arc-seconds	16.46	8.43	18.21	9.66	0.17

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